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ISSUES IN THE STANDARD MODEL*

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ABSTRACT

Focussing on the standard electroweak model, we examine physics issues which may be addressed with the help of intense beams of strange particles.

INTRODUCTION

I was assigned the topic "issues in the standard model," in so far as they are relevant to high intensity sources of strangeness. It is not really clear what is meant by the "standard model" in this context, and, obviously, one of the most important issues in the "standard model" is testing it--in other words, looking for non-standard effects. So I have collected miscellany of issues, starting with some philosophical remarks on how things stand and where we should go from here. I will then focus on a case study: the decay $K^+ \to \pi^+$+nothing observable, which provides a nice illustration of the type of physics that can be probed through rare decays. Other topics I will mention are CP violation in K-decays, hyperon and anti-hyperon physics, and a few random comments on other relevant phenomena.

PHILOSOPHY

One might claim that things have never been better in high energy physics. We have finally achieved a longstanding goal: The elaboration and successful testing of a renormalizable theory of the weak, electromagnetic and strong interactions. We even have indications, specifically the value of the neutral current parameter $\sin^2\theta_w$, that these interactions are unified in a "grand" renormalizable theory. (The response to all this success is, of course, that renormalizability--the erstwhile holy grail--is no longer "in," and many theorists are now working on non-renormalizable theories!)

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One may also argue that things have never been worse. No one believes that the above theories provide the ultimate description of nature. We want to solve the gauge hierarchy problem, understand fermion masses, superunify, find quark and lepton substructures...the problem is that we have gotten ahead of ourselves. There are no data to guide us along these roads--not even monopoles, and as yet few decaying protons. This leaves the way open for wild speculation, which is fun, but doesn't necessarily represent progress.

We clearly need to probe energies higher than those presently accessible in the laboratory. The standard attack in this direction is three-fold:

1) Cosmology. The Big Bang provides the highest energy laboratory around, but the data are not always easy to interpret since they came from a single event in experimental conditions not controlled by us.

2) Let $E_{Lab}\to\infty$. In real life, of course, infinity will be replaced by some practical cut-off Λ_{pr} which is possibly 10's of TeV, but not many orders of magnitude more.

3) Precision measurements at "low" energies: $E_{Lab} << \Lambda_{pr}$. The prime example of this approach is the proton decay search which we believe probes energies up to 10^{14} or 10^{15} GeV. As an example more relevant to this workshop, suppose there were a direct "generation changing" interaction mediated by a boson of mass m_x and coupling with the usual semi-weak strength. Depending on the branching ratios accessible, rare decay searches might probe beyond 10's of TeV, as can be seen by parameterizing some typical branching ratios in terms of m_x:

$$B(K_L\to\mu e) \sim 10^{-12}(100 \text{ TeV}/m_x)^4,$$

$$B(K_L\to\pi^0\mu e) \sim 10^{-12}(170 \text{ TeV}/m_x)^4, \qquad (1)$$

$$B(\Sigma^+\to p\mu e) \sim 10^{-7}(\text{TeV}/m_x)^4 .$$

There are, in addition, still things to be learned about physics at more modest energies. For example, we still don't know how to calculate low energy hadronic matrix elements. Perhaps the confinement/lattice theorists will resolve this difficulty, but new experimental input could certainly be of help. Can high precision measurements and studies of rare processes instruct us on this issue? We are still in the dark concerning the origin of CP violation. Will experiments eventually reveal some small deviation from the superweak predictions?

In discussing these questions in more detail, I will adopt for the most part a desert scenario. The justification for taking this desolate view point is that it provides a well defined yardstick for gauging the experimental accuracy we should aim for. The point is that even the desert has some oases. As we let $E_{Lab} \to \Lambda_{pn}$, we have still (maybe?) to uncover the top quark, for example, and we still have no experimental clue as to the nature of spontaneous gauge symmetry breaking. There is a sort of "unitarity limit"[1] of about a TeV associated with the standard electroweak theory:[2] we must find some evidence for scalar structure at an effective center of mass energy of a TeV or less. The advice I would give to high energy planners is: aim for the hardest thing to find, namely the detection of a "minimal model" Higgs boson in a mass range up to the TeV level. Then you are bound to find something, and hopefully your data will reveal a much richer structure.

By the same token, in thinking about high precision measurements: aim for those tiny effects predicted in the minimal model. If you can measure them, you will in any case learn something, and you may indeed uncover more interesting unexpected phenomena.

$K^+ \to \pi^+ +$ nothing

Following the above line of reasoning, the special interest of this decay mode is that we (almost) know it's there. The minimal model with three generations of fermions predicts a branching ratio

$$B(K^+ \to \pi^+ \nu\bar{\nu}) = 0.7 \times 10^{-10} |1 - x_t|^2, \tag{2}$$

where x_t is the top quark contribution: $x_t = 0$ corresponds to the estimate[3] for the GIM 4-quark model,[4] and

$$x_t \simeq \theta_t \left(\frac{m_t}{m_c}\right)^2 \frac{\ln(m_W^2/m_t^2)}{\ln(m_W^2/m_c^2)} \tag{3}$$

in the K-M 6-quark model.[5] Here and elsewhere we use the formulae valid for $m_t \ll m_W$, which may not be a very good approximation, but it simplifies the discussion and does not significantly affect the order of magnitude estimates we are after.[6] In Eq. (3) we have introduced the parameter

$$\theta_t = (\theta_{dt}\theta^*_{st})/(\theta_{du}\theta^*_{su}), \tag{4}$$

where the θ_{ij} are the relevant elements of the K-M mixing matrix. Since $m_t > 20$ GeV (we take everywhere $m_c = 1.5$ GeV),

$$\ln(m_t^2/m_W^2)/\ln(m_c^2/m_W^2) \lesssim 1/4 \tag{5}$$

and from the observed rate for $K_L \to \mu\mu$ Shrock and Voloshin[7] derived an upper bound which can be expressed as:

$$|\theta_t\ m_t^2/m_c^2| \leq 25. \tag{6}$$

Recent refinements[8,9] give a slightly smaller value, but I prefer to be conservative here since all estimates are rough. The main uncertainty is in the real part of the intermediate 2-γ contribution to $K_L \to \mu\mu$, although if supersymmetry is valid at relatively low energies (hundreds of GeV), there are apparently cancellations[10] which can invalidate[11] the bound (6) altogether. I shall ignore this possibility in the subsequent discussion. By using all available data including the K_L-K_S mass difference,[12] it is possible to bound[9] $|1-x_t|$ from below. However I prefer not to use Δm_K as a constraint, since there are well known uncertainties associated with this analysis. I don't think that one can exclude with certainty at present the possibility that $x_t \simeq 1$, but I consider this perversion of nature as rather unlikely. It would require rather smaller mixing angles than we expect:

$$\theta_t < (0.15)^2 \text{ for } m_t > 20 \text{ GeV, or}$$

$$\theta_t = (0.085)^2 \text{ for } m_t \simeq 35 \text{ GeV.}$$

Since θ_t is related by the unitarity of the K-M matrix to the parameters governing b-decay and ν-induced c- and b- production, precise measurements of B lifetime and branching ratios, and ν-induced mult-lepton events should be able to yield[12,13] reliable lower limits on $|\theta_t|$ and $|1-x_t|$ which are independent of the uncertainties inherent in the analysis of Δm_K.

What do we learn from a measurement of the decay $K^+ \to \pi^+ +$ nothing observable? If we know m_t and θ_t, this decay provides the cleanest available test of weak radiative corrections within the context of the standard model. Alternatively, accepting the theory as correct, a measurement of the decay rate provides an independent constraint on the parameters m_t and θ_t. Finally, if we believe the standard model calculation and have sufficient outside constraints on m_t, θ_t, the decay can be used to probe for new physics. We list some examples.

- Flavor changing currents: A direct decay mediated by a heavy boson of mass m_X would have branching ratio

$$B(K^+ \to \pi^+ \nu_e \bar{\nu}_\mu) \simeq 10^{-10} \left(\frac{26 \text{ TeV}}{m_X} \right)^4, \tag{7}$$

allowing perhaps a probe of masses up to about 25 TeV.

- Neutrino counting:[9] If there are N_ν light ($m_\nu \ll m_K$) neutrinos with the usual weak couplings (and associated leptons of mass $m_L \lesssim m_W$;

for $m_L >> m_W$ only Z^0-exchange contributes and the formula is modified, but the order of magnitude is similar) then the branching ratio for $K^+ \to \pi^+ + \nu\bar{\nu}$ is, from Eq. (2)

$$\sum_{\nu\text{-types}} B(K^+ \to \pi^+ + \nu\bar{\nu}) = \frac{N_\nu}{3} (0.7) |1-x_t|^2 \leq \left(\frac{N_\nu}{3}\right) 5 \times 10^{-9} \tag{8}$$

where we have used the bounds of Eqs. (5) and (6) to get

$$|x_t| \leq 6, \text{ or } |1-x_t| \leq 7. \tag{9}$$

Thus a measured branching ratio exceeding a few $\times 10^{-9}$ could be interpreted[9] as signalling more than three generations of fermions. Alternatively, once we know sufficiently well the parameters θ_t and m_t so as to bound the decay rate per neutrino from below, a measurement of $K^+ \to \pi^+ + \nu\bar{\nu}$ will provide an upper bound on the number of neutrinos, within the context of the standard model.

- Neutrino masses: The branching ratio for the cascade decay $K^+ \to \pi^+ \pi^0$, $\pi^0 \to \nu\bar{\nu}$ is given by[14]

$$B\,(K^+ \to \pi^+ \underset{\to \nu\bar{\nu}}{\pi^0}) = 3.5 \times 10^{-13} \left(\frac{m_\nu}{\text{MeV}}\right)^2 \left[1 - \left(\frac{2m_\nu}{m_\pi}\right)^2\right]^{1/2} . \tag{10}$$

This branching ratio exceeds 10^{-10} if there is a neutrino (e.g. ν_τ) with the usual neutral current couplings in the mass range $m_\nu \simeq (20\text{-}65)$ MeV. This decay is signed by a monochromatic π^+.

- $K^+ \to \pi^+$ +funnies, where the "funnies" are exotic, neutral, non-interacting particles. These could be, for example, a single spin-0 particle or a pair of fermions. This type of decay mode is really the province of the discussion by Wilczek.[15] I shall comment only on non-neutrino fermion pairs which are expected in supersymmetric (susy) theories. Some models entail a photino $\tilde{\gamma}$--the fermionic susy partner of the photon--which is very light. Calculations[14] show that for squark (scalar partners of quarks) masses above 20 GeV [the present lower limit on slepton=(scalar partner of lepton) masses is (16-19) GeV] the branching ratio is

$$B(K^+ \to \pi^+ \tilde{\gamma}\tilde{\gamma}) \leq 10^{-10} \tag{11}$$

except for two special cases. The first of these exceptions is a photino mass range $m_{\tilde{\gamma}} \simeq (2\text{-}65)$ MeV, for which with not-too-heavy squarks one gets, via the cascade decay

$$K^+ \to \pi^+ + \underset{\hookrightarrow \tilde{\gamma}\tilde{\gamma}}{\pi^0} \;, \tag{12}$$

a rate competitive with $K^+\to\pi^+\nu\bar{\nu}$. As for the cascade decay to neutrinos, (12) is signed by a monochromatic π^+. A second exception is the (currently most popular) class of models in which squark masses arise through radiative corrections. If we use a phenomenological Lagrangian, with a "soft" tree-level susy breaking squark mass matrix, the amplitude for $K^+\to\pi^+\gamma\gamma$ is logarithmically divergent,[16] the cut-off being provided by the susy breaking mass scale. In such a scenario the decay rate can be quite large, depending on how far one is willing to push up that scale.

I do not believe that photinos will be sufficiently light to be decayed into by K's in such a scenario. In fact I do not personally believe that--even if supersymmetry is relevant to physics--photinos are sufficiently light for this decay to occur in any scenario. What I do believe in is the importance--short of detecting susy partners of ordinary particles--of excluding their existence in whatever mass range is available to experiment. While there is no evidence as yet that supersymmetry is relevant to nature, there is very little evidence against it--an example of the the free rein for theoretical speculation which I alluded to above.

To summarize this case study, there are three possibilities. 1) The branching ratio for $K^+\to\pi^+ +$ "nothing" is found to lie in the range 10^{-10}-10^{-9}. A precise measurement allows a test of radiative corrections within the minimal model and/or a measurement of the K-M mass matrix parameters. 2) The branching ratio far exceeds 10^{-9}. This signals new physics. It's interpretation lies with the discretion of the reader, but in any case the result is exciting. 3) The decay remains undetected at a level below 10^{-10} in branching ratio. This presumably also implies new physics but will be no more helpful than, for example, the lack of detection of proton decay. I optimistically consider this last possibility as unrealistic.

CP VIOLATION IN K-DECAYS

There is no question that precision measurements in the decays $K_{L,S}\to 2\pi$ are highly desirable. They will 1) further constrain deviations from CPT invariance, a fundamental symmetry of the local Lagrangian theories which we take for granted, and 2) hopefully reveal a small deviation from the predictions of the "superweak" model, in which all CP violating effects are in neutral meson mass mixing parameters. In discussing these effects I shall follow the dictum outlined above: ask what are the tiny effects expected in the "minimal model." If we can detect these, we can also detect grosser deviations from them, and so we are sure to learn something. Furthermore, I shall argue that if we analyze the data within the context of the minimal model, insofar as CP violating effects are observable at all, their measurement can shed light on the still ill-understand dynamics of weak interactions, and, in particular, on the persisting mystery of the $|\Delta I|=1/2$ rule.

In the present context we understand as the "minimal model" the so-called K-M model of CP-violation in which CP violating phases appear originally in Yukawa couplings of fermions to the Higgs particle, and, upon diagonalization of the fermion mass matrix, are shifted to the charged current (K-M) coupling matrix. As is well known, in this model observable CP violating effects require the existence of at least three generations of fermions. As a result, any observable CP violating effect must know about the presence of b,t quarks. To lowest order in the weak interactions, such effects occur only through "penguin" diagrams. Here we designate as "penguin diagrams" the generic class of diagrams in which the transition $d \to s$ occurs along a quark line in a bound quark (hadronic) system via $W^{\pm}$ exchange with the intermediate (u,c,t) quark system interacting with other bound quarks through gluon exchange. Within this picture we can roughly parameterize the "direct" (as opposed to superweak=mass mixing) CP-violating contribution to a decay amplitude by:

$$\frac{\mathrm{Im}A}{\mathrm{Re}A} \sim f_P x_\delta \equiv f_P \; s_2 s_3 \; \sin\delta \; \ln\left(\frac{m_t^2}{m_c^2}\right) , \tag{13}$$

where f_P represents the fractional contribution of penguin diagrams to the process considered, and θ_i, $s_i = \sin\theta_i$, and δ are parameters in the K-M matrix. The combination of parameters in Eq. (13) (where we have assumed the validity of a small angle approximation) can be expressed, for example as:

$$s_2 s_3 \; \sin\delta \simeq - \; \mathrm{Im}\theta_{sc} \simeq \mathrm{Im}\theta_t^{*} \; . \tag{14}$$

Because penguin diagrams involve an $s \to d$ transition with I-spin conserving gluon emission, the CP-violating phase arises only in $|\Delta I| = 1/2$ transitions. This leads[17,18] to a phase difference between, for example, the amplitudes for I=0 and I=2 final states in $K^0 \to 2\pi$.

The superweak contribution to CP violation in neutral kaon decay arises from a $K^0 \to \bar{K}^0$ term in the neutral kaon mass matrix. The CP violating parameter can be expressed as[17]

$$\varepsilon_m = \frac{\mathrm{ImAmpl.}(K^0 \to \bar{K}^0)}{\Delta m_K} \simeq 2 s_2 s_3 \sin\delta \left[\ln\left(\frac{m_t^2}{m_c^2}\right) - 1 - \theta_t \; \frac{m_t^2}{m_c^2} \right] , \tag{15}$$

using the same approximations[6] as before. For the denominator we use the original estimate[3] of Δm_K in a 4-quark flavor model, simply because this gives the right answer to within 30% for $m_c = 1.5$. For the numerator, the free quark model estimate is a reasonable approximation except for the uncertainty[19] in evaluating the matrix element between kaon states of the effective quark operators. This gives an uncertainty in an overall multiplicative factor of order unity. Further strong interaction corrections[20] modify by factors O(1) the coefficients of the various terms in brackets in Eq. (15). Finally, the quantity relevant to experiment is not ε_m but

$$e^{-i\pi/4}\ \epsilon \simeq \frac{1}{\sqrt{2}}\,\epsilon_m + \sqrt{2}\,\xi_{2\pi,I=0} \simeq 2\times 10^{-3} \qquad (16)$$

where $\xi_{2\pi,I=0}$ is the CP-violating phase in the decay of K^0 into an I=0 dipion state. In the commonly used Wu-Yang convention this phase is set equal to zero and ϵ_m is redefined by the shift (16). This gives an additional (small[20]) change in the coefficient of the log term in (15). For the sake of order of magnitude arguments I shall use (15) as is without corrections. The point I wish to make is simply that since

$$\ln\left(\frac{m_t^2}{m_c^2}\right) > 5 \text{ for } m_t > 20 \text{ GeV}, \qquad (17)$$

the bound (6) implies that the log term in (15) contributes at least a fifth of the total magnitude. Thus we expect

$$|x_\delta| \simeq (0.2\text{-}1)\,\frac{1}{\sqrt{2}}\,\epsilon \simeq (0.3\text{-}1.4)\times 10^{-3}\ . \qquad (18)$$

In other words we expect deviations from superweak theory to occur at a level

$$|f_P x_\delta| \sim 10^{-4\pm1} \qquad (19)$$

which is the level of detection experimenters should aim for.

Two alternative optimal scenarios would be: a) Direct CP violating effects are found at a level considerably larger than 10^{-3}. This would suggest that the standard K-M model is incorrect and signal new physics, fun and excitement. b) Effects at the expected level of 10^{-4} are measured. When m_t and the K-M angles s_1, s_2 are determined independently, the parameters f_P and δ can be extracted from the analysis of CP violating phenomena. This will have the bonus of determining the importance of penguins and perhaps contribute to our understanding of non-leptonic decay dynamics.

But alas, as we see below, measurable effects which are proportional to $f_P x_\delta$ tend to be suppressed by other factors.

The most promising place to look for a deviation from superweak theory is still in the $K_{L,S}\to 2\pi$ decay. In this processes the deviation is characterized by the parameter ϵ':

$$|\epsilon'| = \frac{1}{\sqrt{2}}\,\left|f_P x_\delta\,\frac{A(I=2)}{A(I=0)}\right| \simeq \frac{1}{25}\,|f_P x_\delta| \qquad (20)$$

where the last factor includes the measured suppression of the I=2 final state relative to I=0. The present experimental limit is usually quoted as

$$\left| \frac{\varepsilon'}{\varepsilon} \right| \lesssim \frac{1}{50} , \tag{21}$$

while the above analysis suggests

$$\left| \frac{\varepsilon'}{\varepsilon} \right| \simeq \frac{1}{25} f_P \frac{x_\delta}{\varepsilon} \simeq \frac{f_P}{50} \left(\frac{1}{2} -2 \right), \tag{22}$$

so we expect the next round of experiments to show a non-zero effect, thus providing information on f_P.

For $K\to 3\pi$, the amplitudes are completely determined in terms of the (real, by convention) amplitude for $K\to 2\pi(I=0)$, using the $\Delta I=1/2$ rule and chiral symmetry. Thus "direct" CP violation can arise only to the extent that one of these is inexact, and we expect effects no larger than $10^{-1} f_P x_\delta < 10^{-4}$.

Rare K-decays which can proceed only via higher order processes with internal quark loops can have a relatively enhanced CP-violation. Unfortunately the decay rates for the interesting cases are exceedingly small. For example, the measured branching ratio for $K^+\to\pi^+e^+e^-$ agrees fairly well with the (somewhat questionable in this case) estimate using free quarks.[3] The same model gives[3,17]

$$\Gamma(K_1\to\pi^0 e^+e^-) \simeq (K^+\to\pi^+ e^+e^-),$$

$$\varepsilon'_{\pi ee} = \frac{\Gamma(K_2\to\pi^0 e^+e^-)}{\Gamma(K_1\to\pi^0 e^+e^-)} \simeq x_\delta \simeq (0.2\text{-}1)\ \varepsilon/\sqrt{2}, \tag{23}$$

i.e. a fairly large ε'/ε ratio, but the expected K_L branching ratio from the direct decay is only:

$$B(K_2\to\pi^0 e^+e^-) \sim (1\text{-}5) \times 10^{-12} . \tag{24}$$

Similarly, the (here more reliable) quark model estimate gives[3,17]

$$\Gamma(K_1 \to \pi^0 \nu\bar{\nu}) \simeq \Gamma(K^+ \to \pi^+ \nu\bar{\nu})$$

$$\varepsilon'_{\pi^0\nu\bar{\nu}} = \frac{\Gamma(K_2 \to \pi^0 \nu\bar{\nu})}{\Gamma(K_1 \to \pi^0 \nu\bar{\nu})} \simeq \varepsilon \frac{m_t^2}{m_c^2} \frac{\ln(m_W^2/m_t^2)}{\ln(m_W^2/m_c^2)} \frac{1}{[\ln(m_t^2/m_c^2) - 1 - \theta_t]}$$

$$\frac{\varepsilon'_{\pi^0\nu\bar{\nu}}}{\varepsilon} \simeq (1\text{-}10) \qquad (25)$$

where the optimistic factor 10 assumes $x_S \simeq \varepsilon/\sqrt{2}$, $m_t \simeq 35$ GeV. Even in this case, the $K_L \to \pi\nu\bar{\nu}$ branching ratio is not expected to exceed 10^{-13}. Of course K_L, K_S interference effects will be very pronounced in these decays. All one needs is to make a beam of 10^{13} K_S per pulse!

I list these numbers to show where minimal expectations lie. I leave it as a challenge to experimenters to attempt to measure such tiny effects, and to theorists to think of something better.

HYPERON DECAY

I submit that not much can be learned by improving experimental precision on non-leptonic decay amplitudes (aside from phases). I suspect that the present experimental errors are smaller than any conceivable accuracy theorists will ever achieve in calculating these amplitudes.

There is however some interest in improving accuracy on non-leptonic decay parameters. One would like to study SU(3) breaking corrections to the Cabbibo model and improve limits on deviations from it such as the presence of right-handed currents.[21] There is in fact a reported discrepancy[22] in $\Sigma^- \to ne^-\bar{\nu}_e$ which is yet to be resolved.

Studies of radiative decays might contribute to our understanding of non-leptonic decay dynamics. Experiments show a large SU(3)-forbidden asymmetry (with large errors) in the decay $\Sigma^+ \to p\gamma$, and improved precision is needed to clarify this issue. A concerted study of the various radiative decay modes, including $\Xi^- \to \Sigma^-\gamma$, $\Xi^0 \to \Lambda\gamma$, $\Sigma^0\gamma$, $\Lambda \to n p$, would address the issues of "long distance" decay dynamics (penguins and all that) because the short distance contribution, i.e. the magnetic transition $d \to s + \gamma$, is highly suppressed by helicity conservation of gauge couplings. A word of warning however; the baryon pole contribution, which measures directly the weak $B \to B'$ transition, is not expected[23] to dominate over direct emission contributions in charged hyperon decay, and the limited data available[24] suggests that the same is true for neutral hyperon radiative decay. So interpretation of the data may be less than straightforward.

Finally, one can look for time reversal violation[25] by measuring the relative phase between s- and p-wave amplitudes. A deviation from the phase difference arising from strong rescattering in the final state is a sign of T-violation. Again one would want to aim for an accuracy of better than 10^{-3} in the measured phase.

ANTI-HYPERON DECAY

Comparison between hyperon and anti-hyperon lifetimes provide a test of CPT but this is unlikely to be competitive with tests provided by $\tau_{\pi^\pm}$ and especially by precision measurements in the neutral kaon system.

While CPT invariance requires equal total decay rates for hyperon and anti-hyperon, CP violation can induce differences in partial rates if there is more than one open channel and if these communicate via strong interactions. Thus for $Y\to N\pi$ there are two final state channels $I=1/2,\ 3/2$, which are eigenstates of the strong S-matrix, while the specific charge modes (e.g. $n\pi^0$, $p\pi^-$) are not. Then one gets a decay asymmetry:

$$A = \frac{\Gamma(Y\to N\pi)-\Gamma(\bar{Y}\to\bar{N}\bar{\pi})}{2\Gamma(Y\to N\pi)} \sim \sin\phi\,\sin\delta\,\frac{2|A_{3/2}||A_{1/2}|}{|A_{3/2}|^2+|A_{1/2}|^2} \qquad (26)$$

where $\delta=\delta_{3/2}-\delta_{1/2}$ is the difference between strong interaction phase shifts in the $I=3/2,\ 1/2$ final states and $\phi=\phi_{1/2}-\phi_{3/2}$ is the difference in CP violating phases. In the standard K-M model we expect

$$\phi_{3/2} = 0,\ |\phi_{1/2}| \simeq |f_P^{(B)} x_\delta| \qquad (27)$$

where $f_P^{(B)}$ is the fractional importance of penguins in baryon decays (generally unequal to $f_P^{(K)}$, but presumably similar in order of magnitude). Note that in addition to non-vanishing ϕ and δ, an appreciable effect depends on $A_{1/2,3/2}$ having similar strength. Herein starts the difficulty.

For[25] $\Lambda\to N\pi$, the $\Delta I=1/2$ rule suppresses the $I=3/2$ final state; from experiment

$$|A_{3/2}/A_{1/2}|_\Lambda \simeq 0.03. \qquad (28)$$

For the decays $\Sigma\to N\pi$ both $I=3/2$ and $I=1/2$ final states are allowed by the $\Delta I=1/2$ rule. However for p-waves the near vanishing of the $\Sigma^-\to n\pi^-$ amplitude tells us that

$$|A_{3/2}/A_{1/2}|_{\Sigma(\text{p-wave})} \simeq 0.05. \qquad (29)$$

In addition we expect $\delta \ll 1$ for p-waves. For s-waves the strong phase shift δ could be appreciable, and we know that $|A_{3/2}| \sim |A_{1/2}|$. However, if one believes that s-wave baryon decays are correctly described by soft pion theorems, then the amplitude for $\Sigma^+ \to n\pi^+$, which is a specific linear combination of I=1/2 and 3/2, vanishes separately for penguin and the $\Delta I=1/2$ part of non-penguin contributions. This means that

$$f_P^{(3/2)} = f_P^{(1/2)} \tag{30}$$

up to violations of $\Delta I=1/2$ and/or the soft pion limit. This in turn implies that $A_{1/2}$ and $A_{3/2}$ have equal phases to the same approximation:

$$(\phi_{3/2}-\phi_{1/2})_{\Sigma(\text{s-wave})} = O(10^{-1} f_P^{(\Sigma)} x_\delta) < 10^{-4} \tag{31}$$

Again, however, if effects as small as (31) could be detected, their measurement could contribute to our understanding of the decay dynamics. I close this section with the same challenge to theorists and experimentalists as above.

RANDOMONIA AND CONCLUSION

There is a strong theoretical prejudice that the Higgs scalar of the minimal electroweak model must have a mass

$$m_H \gtrsim 10 \text{ GeV}. \tag{32}$$

While well founded and highly plausible, the bound (32) is not a rigorous theorem. To my knowledge the experimental bound is still

$$m_H \gtrsim 15 \text{ MeV}. \tag{33}$$

A search[26] for

$$K^+ \to H + \pi^+, \quad H \to e^+e^-$$

is on the edge of ruling out $m_H < 2\,m_\mu$, but the branching ratio $\lesssim 4\times10^{-8}$ is not quite conclusive.[27] Studies of

$$K_L \rightarrow \begin{cases} \pi^0 e^+ e^- \\ \pi^0 \mu^+ \mu^- \\ \pi^0 \gamma\gamma \end{cases}$$

at a branching ratio level of 10^{-10}-10^{-11} would eliminate with certainty the possibility that $m_H < 2m_\pi$.

The decay $K_L \rightarrow \mu\mu\gamma$ should be competitive with $K_L \rightarrow \mu\mu$ as it is lower order in α although disfavored by phase space. It could provide a laboratory for studying the $\mu^+\mu^-$ bound state.[28]

Finally, it has been suggested[29] that we should not limit our considerations to weak interactions, and that, for example, a precision measurement of fixed angle K-N scattering (at more than "medium" energy, however) could provide nice QCD tests.

I will simply conclude by arguing that there is a good deal to be learned from high intensity sources of strangeness. I leave it to the reader to judge whether the levels of precision suggested by the "standard model" issues are attainable and/or desirable.

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